
HQ design and analysis

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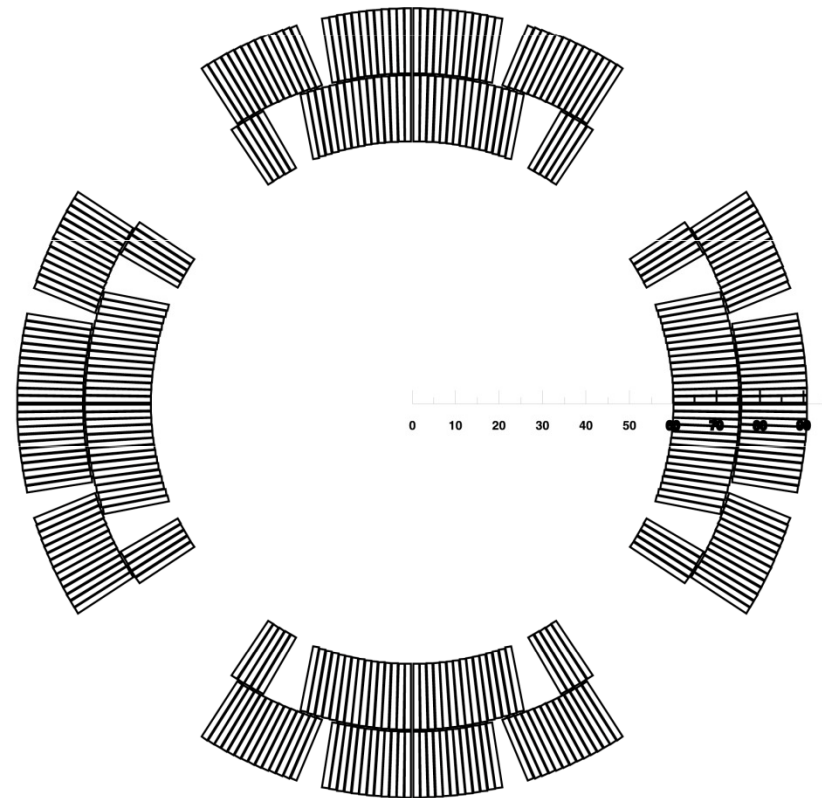
LARP Collaboration Meeting
Napa Valley, CA
April 8-10, 2009

Outline

- Magnet design
- Magnetic analysis
 - Conductor peak field
 - Magnet parameters
 - Field quality and saturation effect
- Mechanical analysis
 - Pre-load conditions
 - Coil and structure stress
- Conclusions

Cable and coil design

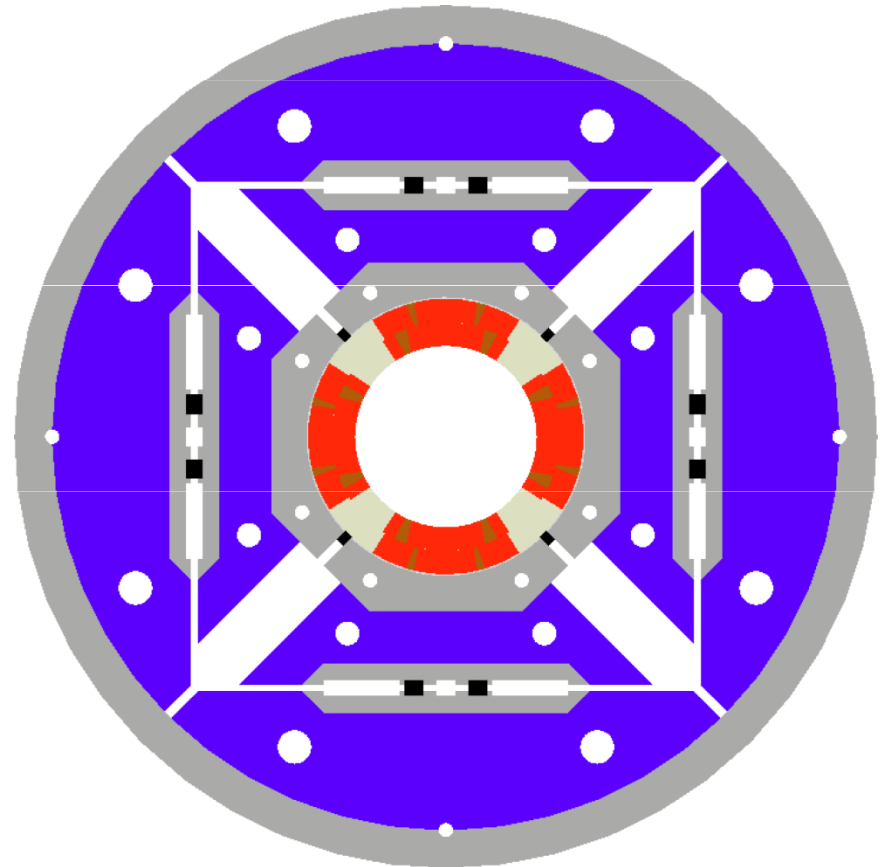
- Cable
 - 35 strands
 - Width: 15.150 mm
 - Mid-thickness: 1.437 mm
 - Keystone angle: 0.750
 - Insulation thick.: 0.1 mm
- Coil
 - Aperture: 120 mm
 - 4 blocks
 - 46 turns



Magnet design

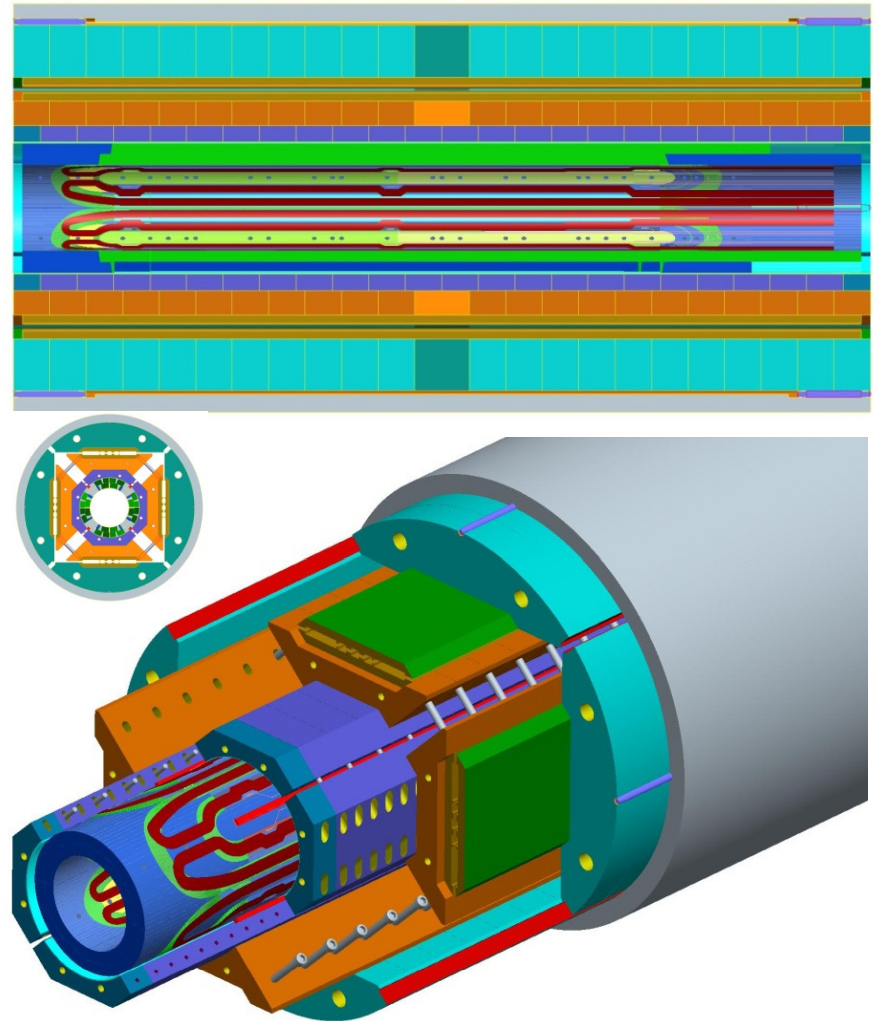
Cross-section

- Aluminum shell
 - 25 mm thick
 - OD = 570 mm
- 4-split iron yoke
- Bolted iron pads
 - Gaps for coil end support and cooling channels
- Iron masters
 - 2 bladders 50 mm wide
 - 2 interference keys
- Bolted aluminum collars for azimuthal alignment
- G10 sheet between coil and collars



Magnet design 3D components

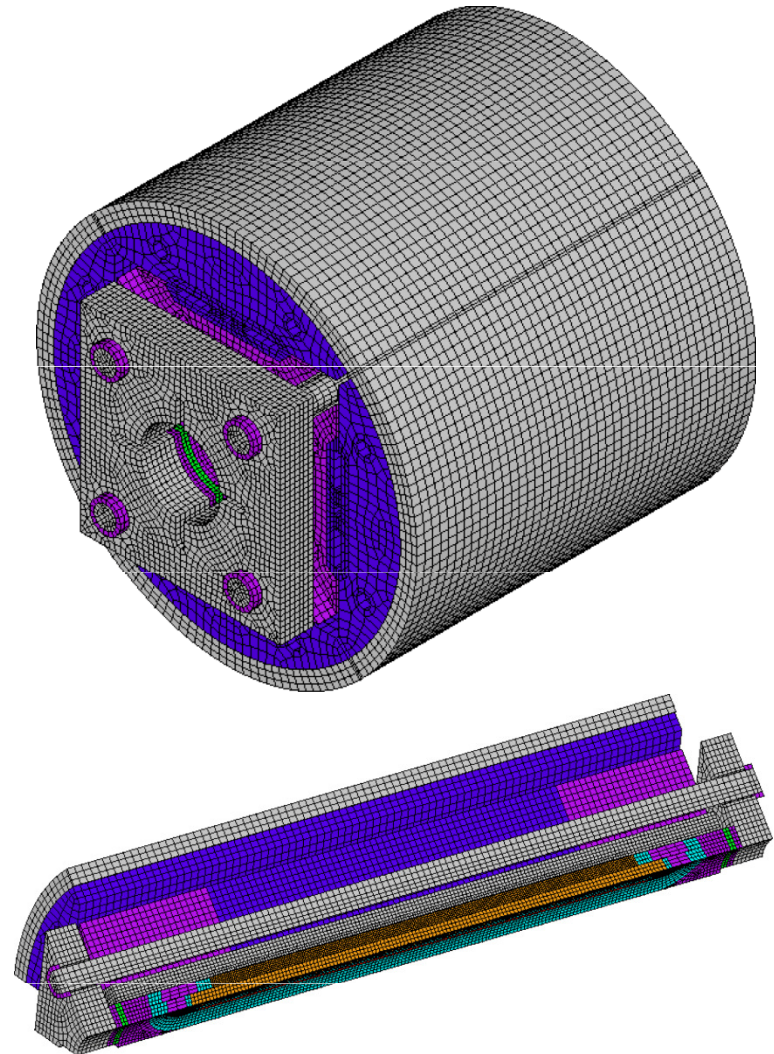
- Yoke laminations, 50 mm thick with tie rods
- Iron pad laminations, 50 mm thick tie rods
- Collar laminations, 50 mm thick with tie rods
- Iron masters
 - Easy insertion and removal of coil pack (large clearance)
 - Continuous surface
 - Pad-yoke alignment
 - Improved tolerances



Magnet design

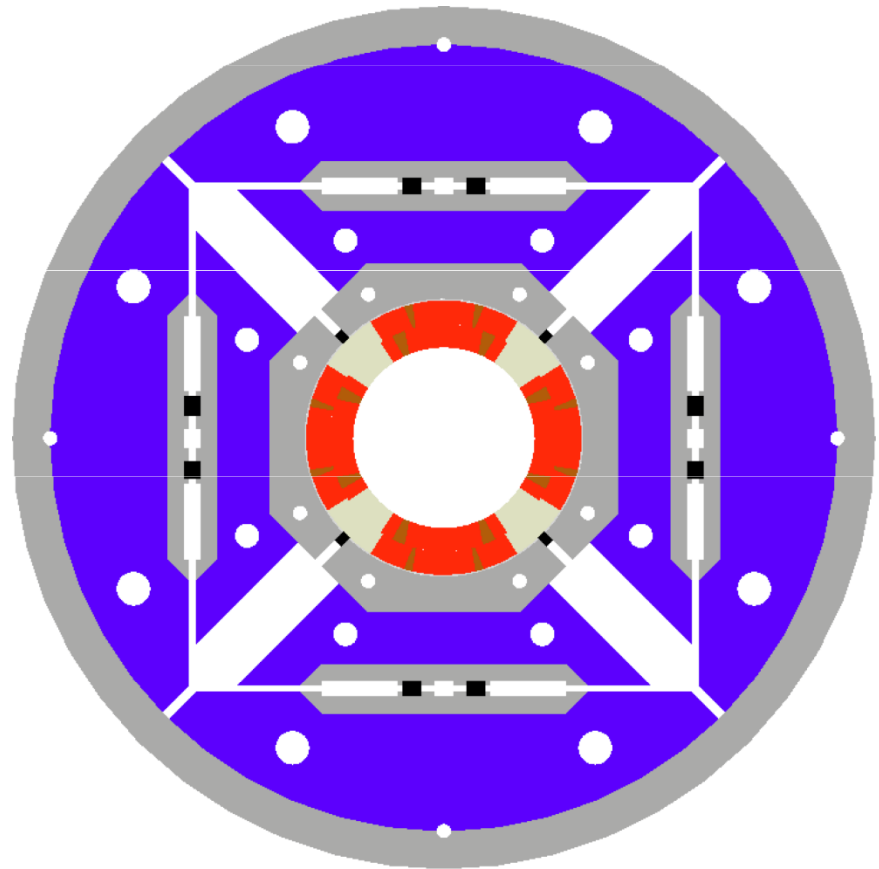
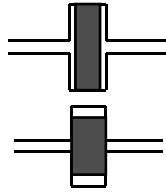
Axial support

- Stainless steel (Nitronic 40) end plate
 - 50 mm thick
- Aluminum axial rods
 - 34 mm diameter
- Axial pre-load provided by additional plate and piston
 - Piston actuated to spread apart the two end plates
 - Nuts to lock the pre-compression



Magnet design Alignment

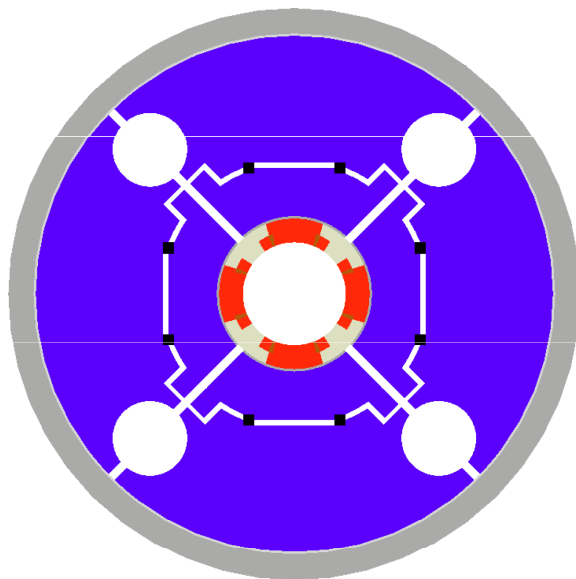
- Pins shell – yoke
- Master keys pad – yoke
 - Trapezoidal shape
 - Interference keys
 - Alignment keys
- Pad – Collar
- Collar – coil
 - Alignment keys
 - Under compression from assembly to excitation



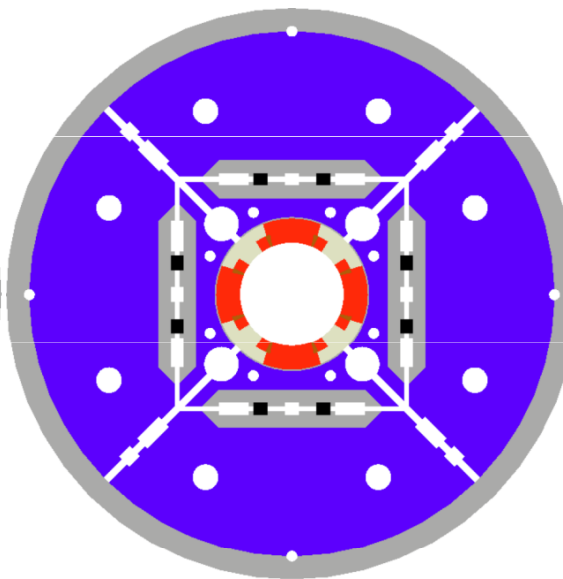
Magnet design

From TQS to HQ

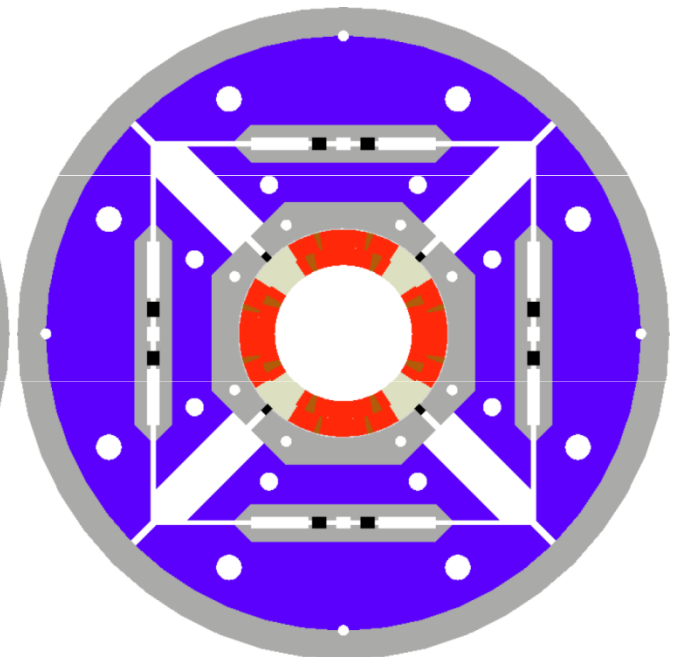
TQS



LQS



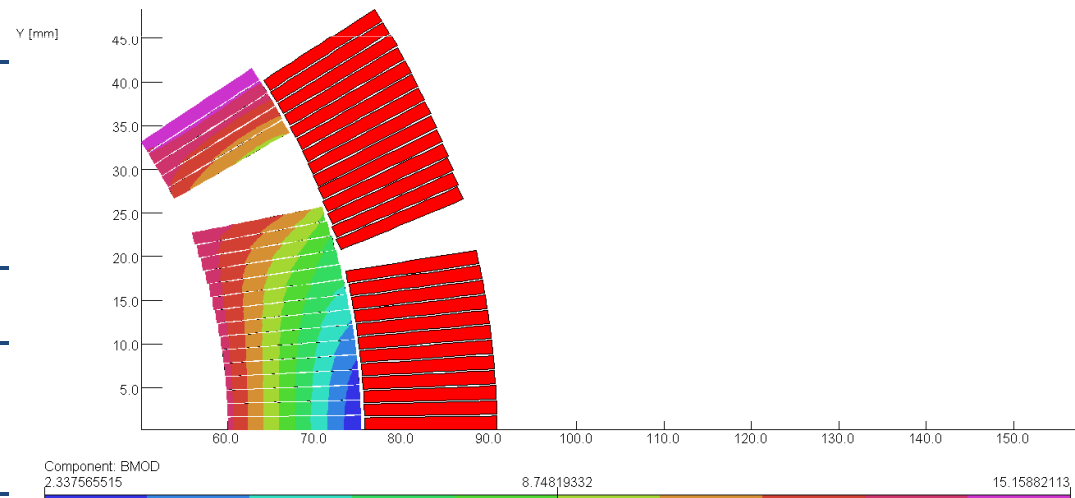
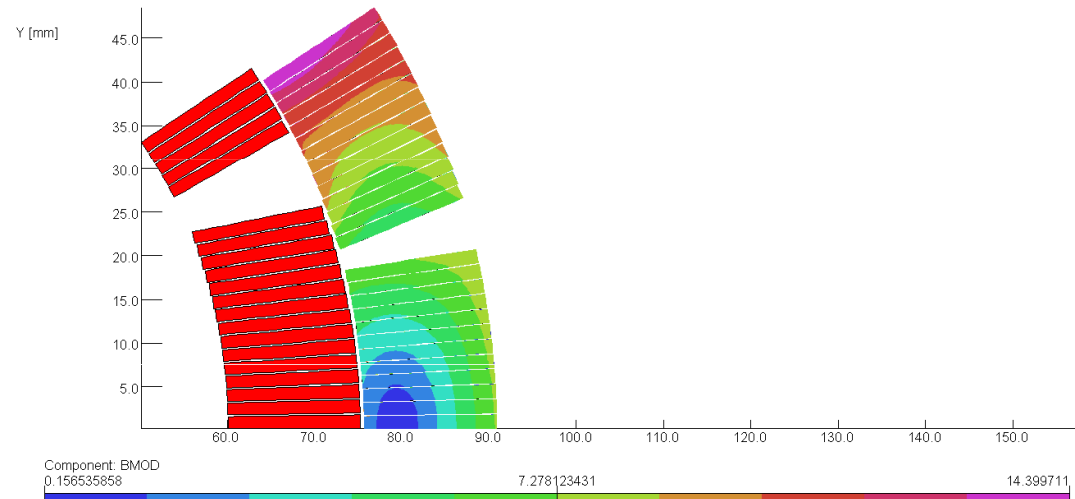
HQ



2D magnetic analysis

Conductor peak field and magnet parameters

- J_c of 3000 A/mm² (4.2 K, 12 T)
- About 0.7 T difference between layer 1 and layer 2

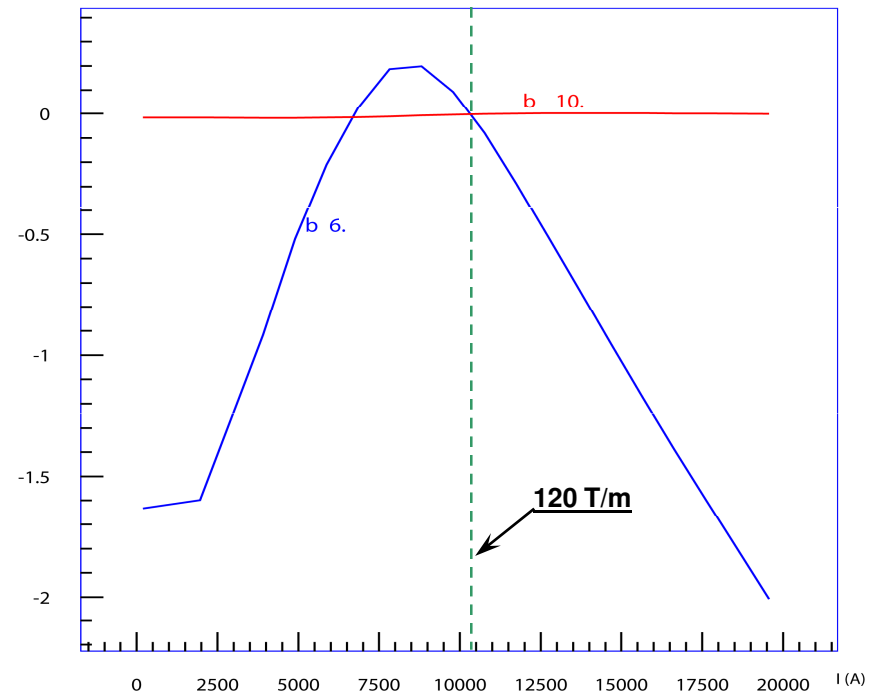
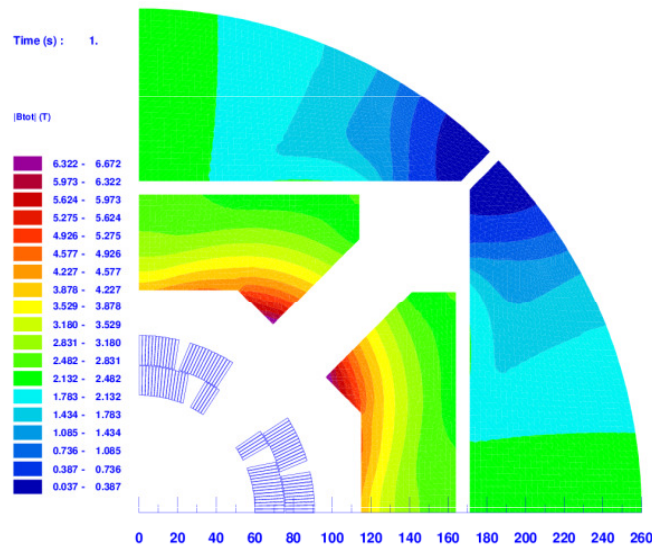


Temp.	Current	Grad.	Layer 1	Layer 2	Stored energy
			Peak field	Peak field	
K	kA	T/m	T	T	kJ/m
4.4	17.73	199	13.90	13.24	1174
1.9	19.45	219	15.17	14.45	1405

2D magnetic analysis

Iron saturation and field quality

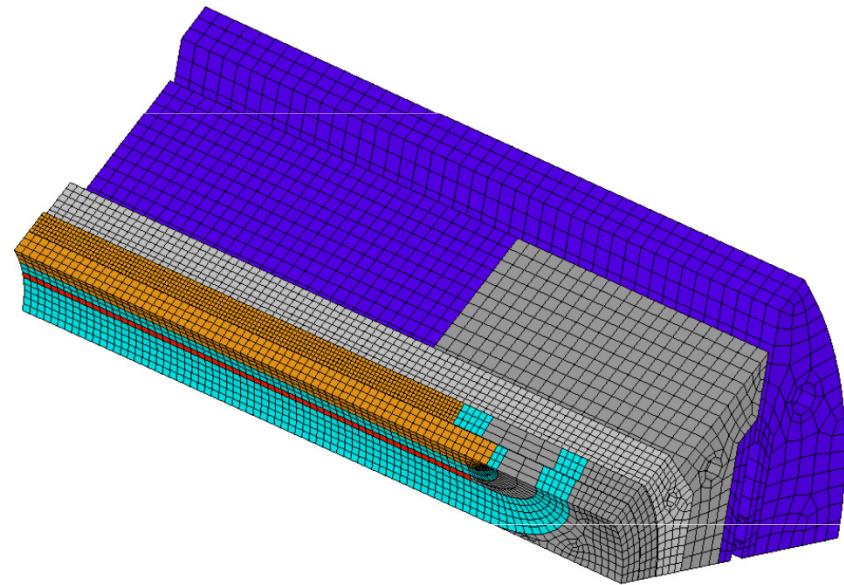
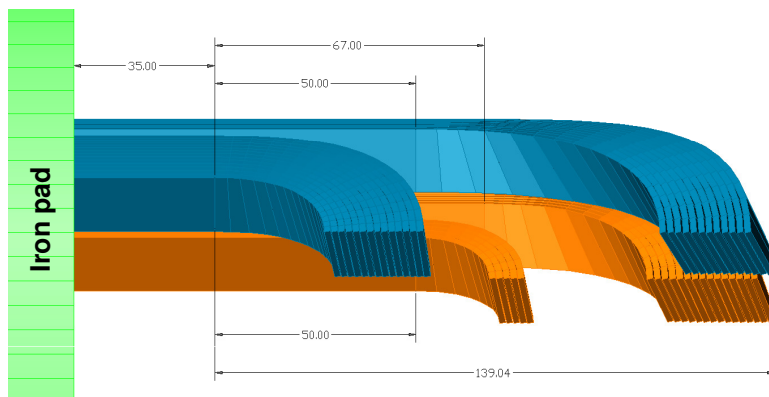
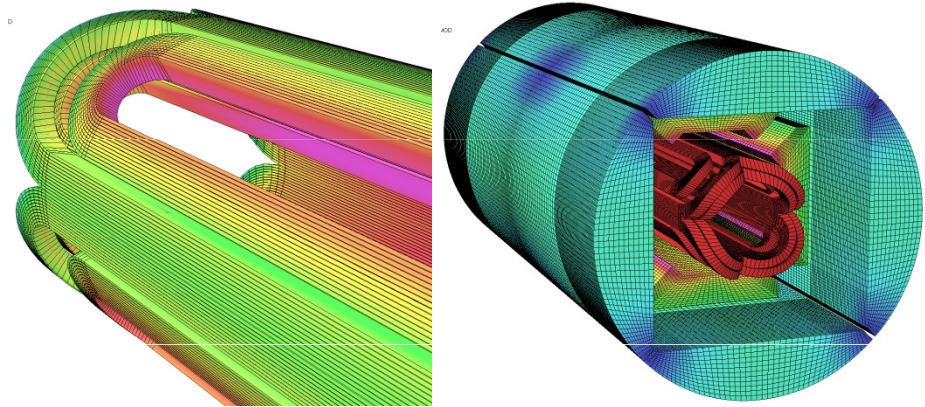
- $R_{\text{ref}} = 40 \text{ mm}$
- At 120 T/m
 - All allowed harmonics below 0.5 units
- Saturation effect
 - $b_6 \pm 1$ unit from 0 to 20 kA



3D magnetic analysis

Conductor peak field

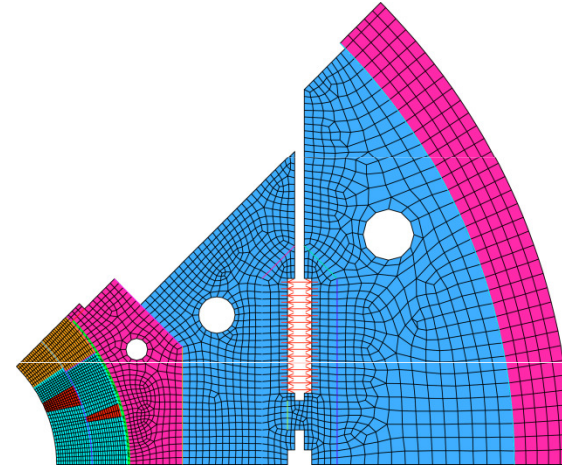
- Peak field in the end located on pole turn, layer 2
- Stainless steel pad over ends
 - About 1% lower peak field in the end with respect to straight section



2D mechanical analysis

Parameters and model

- Computational steps
 - Bladder pressurization
 - Key insertion
 - Cool-down
 - Excitation
- Impregnated coil surfaces: bonded
- All other surfaces: 0.2 friction factor
- Contact pressure (or tension <20 MPa) between pole and coil
- Two gradient considered
 - 219 T/m: limit conditions
 - 180 T/m: coil peak stress <150 MPa

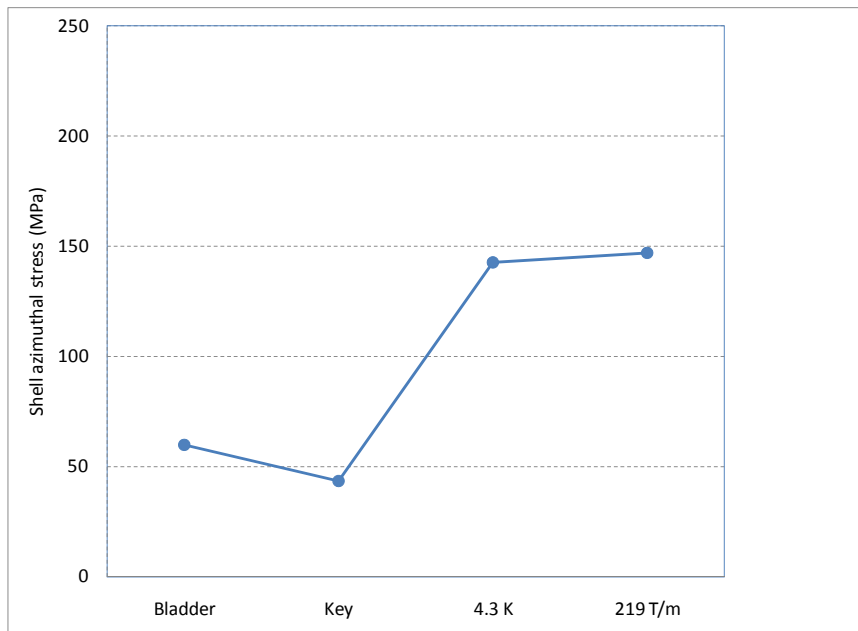


	Grad	T/m	180	219
Layer 1	Fx	N/mm	+2187	+3234
	Fy	N/mm	-1243	-1853
	Fr	N/mm	+1620	+2389
	Ft	N/mm	-1753	-2609
Layer 2	Fx	N/mm	+76	+18
	Fy	N/mm	-2103	-3131
	Fr	N/mm	-724	-1171
	Ft	N/mm	-2097	-3100

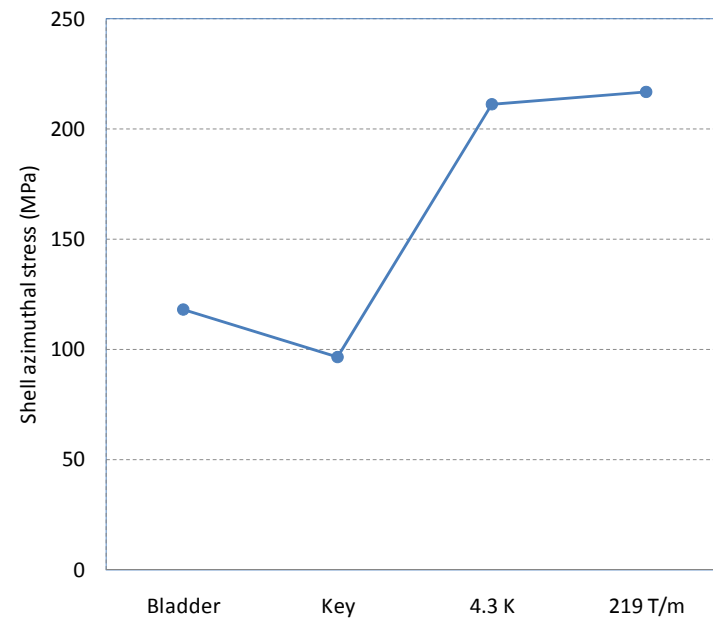
2D mechanical analysis

Bladder pressure and shell tension

- Pre-loading for 180 T/m
 - Bladder pressure: 23 MPa
 - Key interference: 0.3 mm
 - Shell tension:



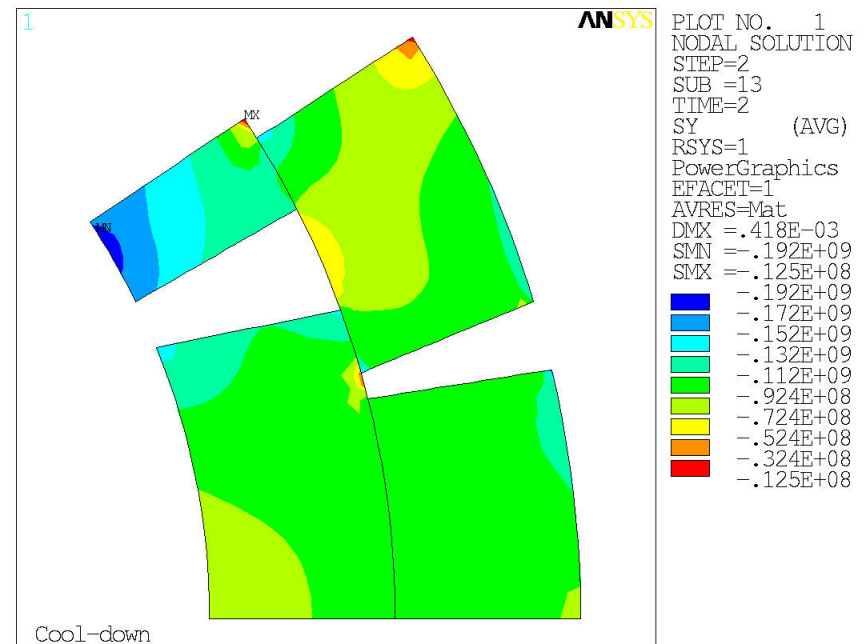
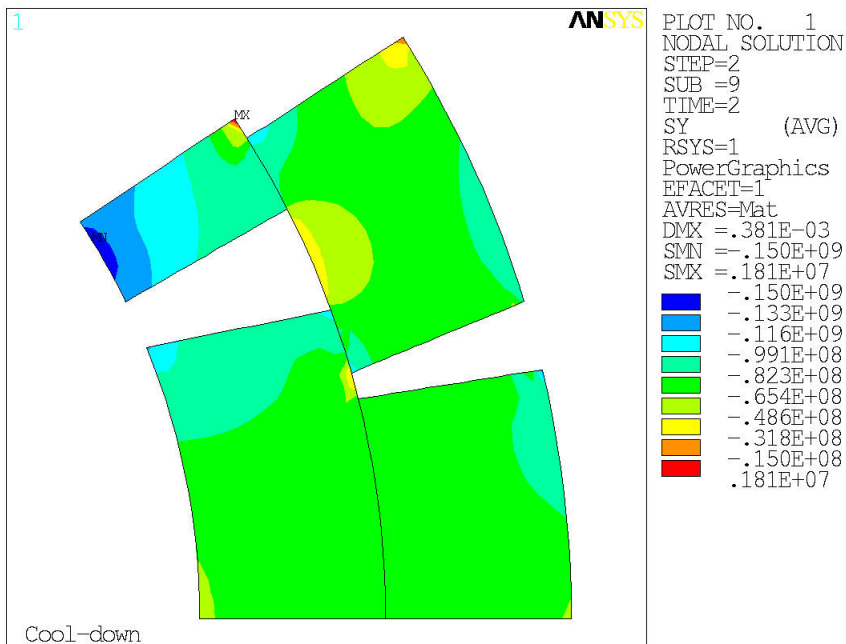
- Pre-loading for 219 T/m
 - Bladder pressure: 46 MPa
 - Key interference: 0.6 mm
 - Shell tension:



2D mechanical analysis

Coil peak stress after cool-down

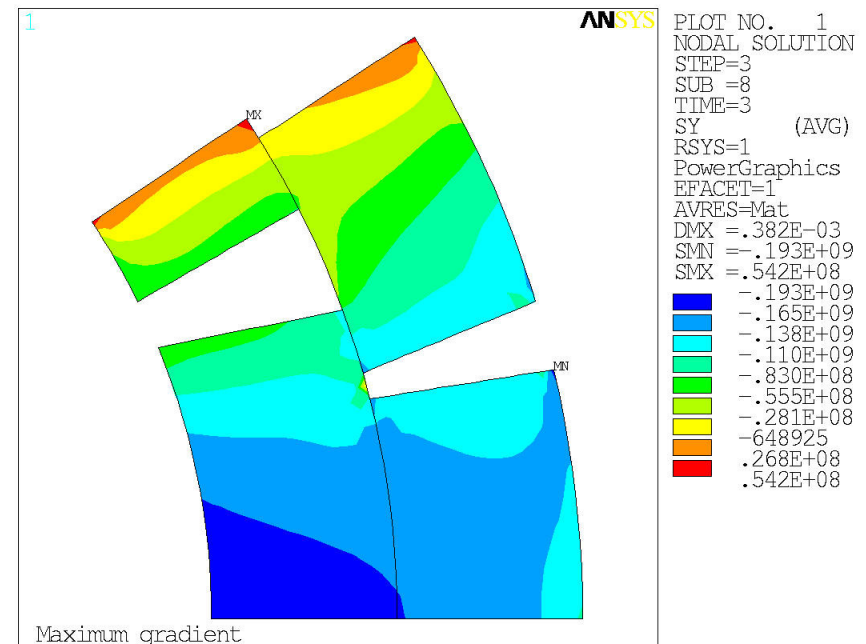
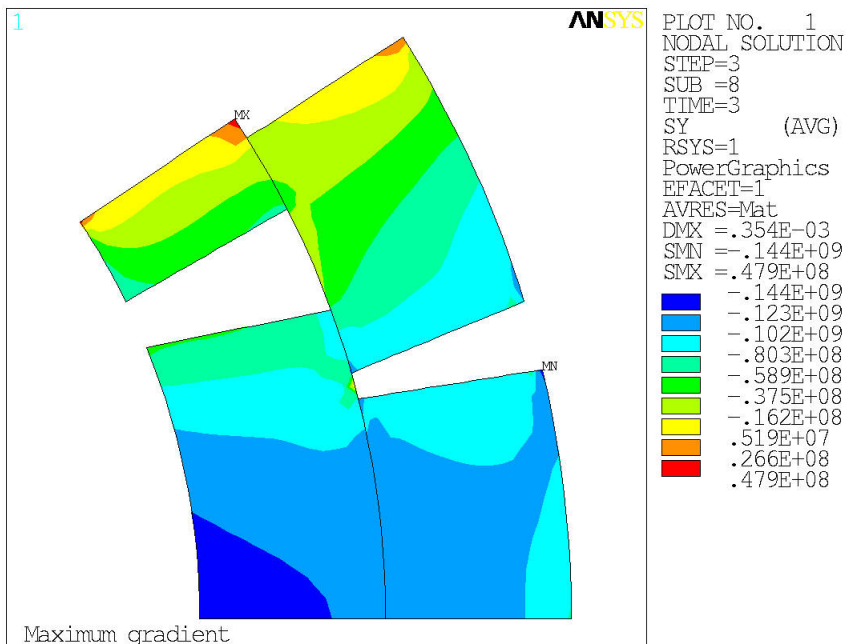
- Pre-loading for 180 T/m
 - Coil peak stress: 150 MPa
 - Pole area, inner radius, layer 1
- Pre-loading for 219 T/m
 - Coil peak stress: 192 MPa
 - Pole area, inner radius, layer 1



2D mechanical analysis

Coil peak stress with e.m. forces

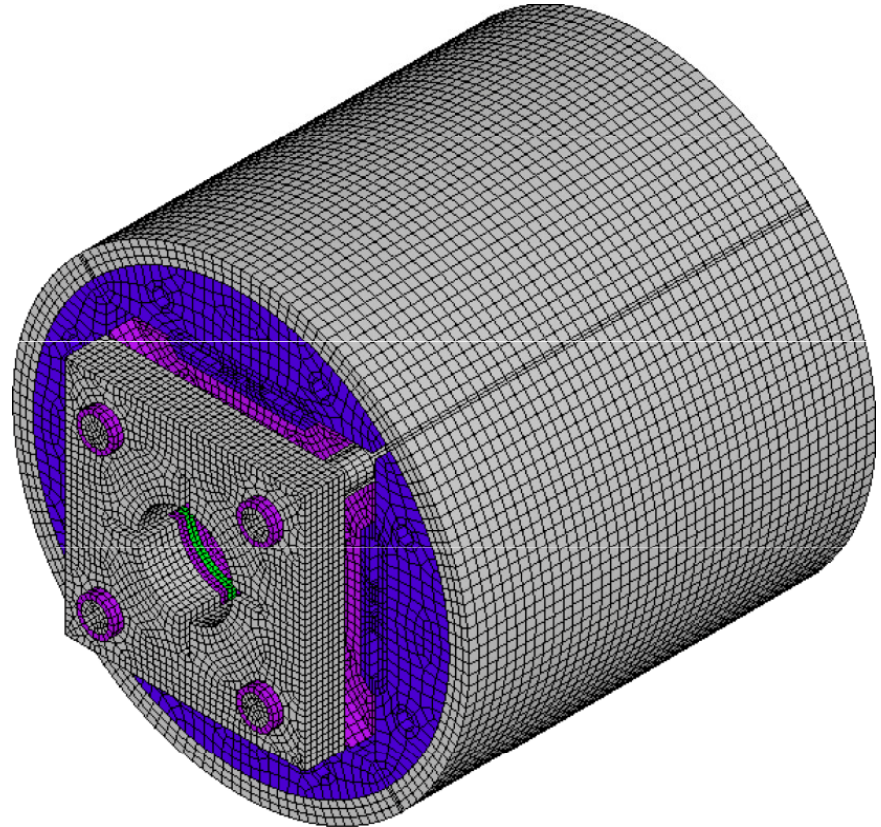
- Pre-loading for 180 T/m
 - Coil peak stress: 144 MPa
 - Mid-plane, inner radius, layer 1
- Pre-loading for 219 T/m
 - Coil peak stress: 193 MPa
 - Mid-plane, inner radius, layer 1



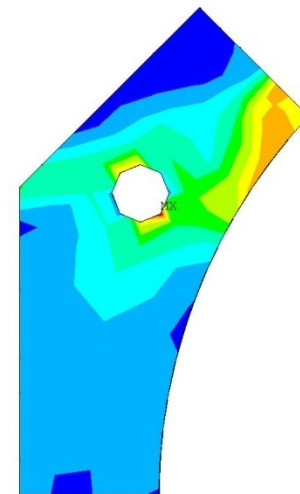
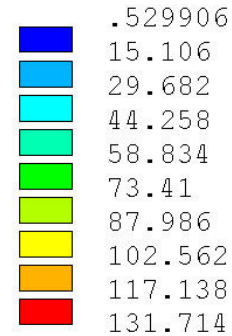
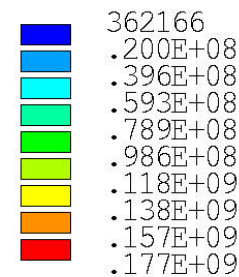
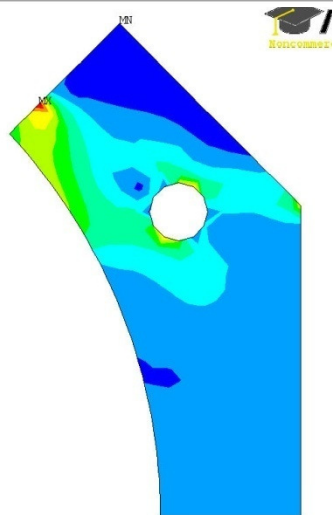
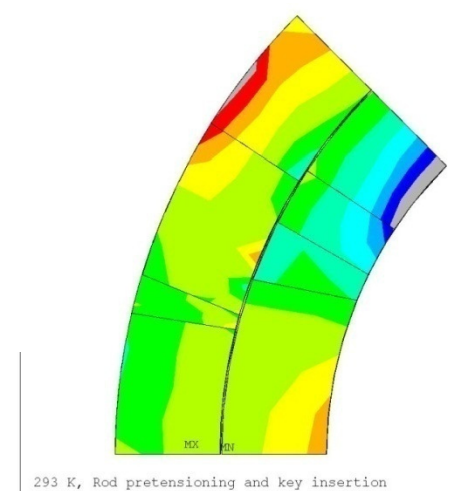
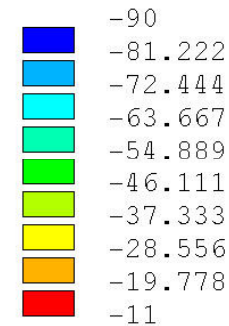
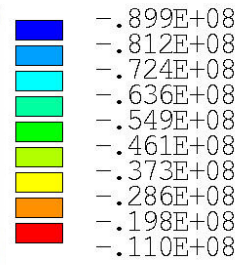
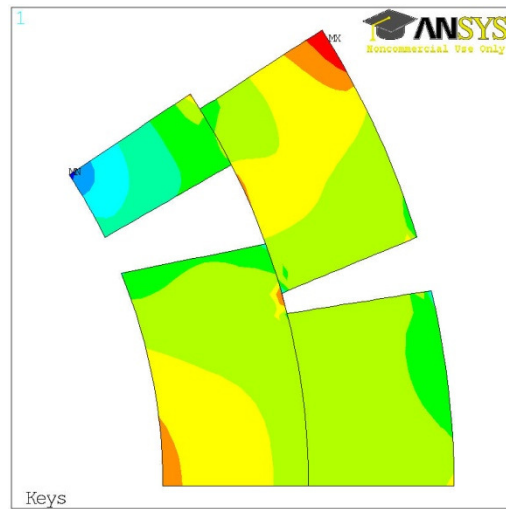
3D mechanical analysis

Parameters and model

- Computational steps
 - Bladder pressurization
 - Key insertion
 - Cool-down
 - Excitation
- Impregnated coil surfaces: bonded
- All other surfaces: 0.2 friction factor
- Contact pressure between pole and coil



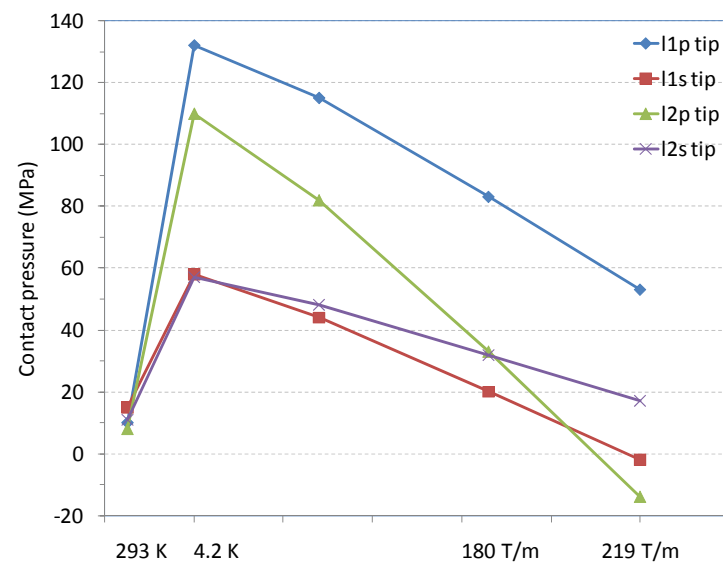
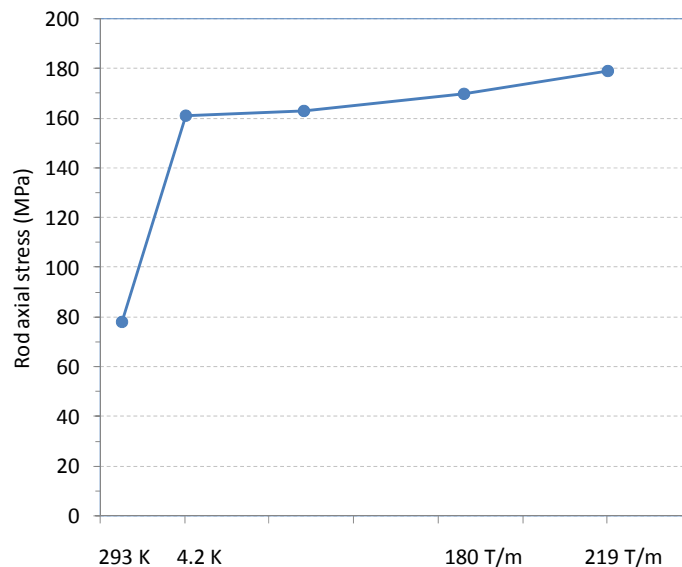
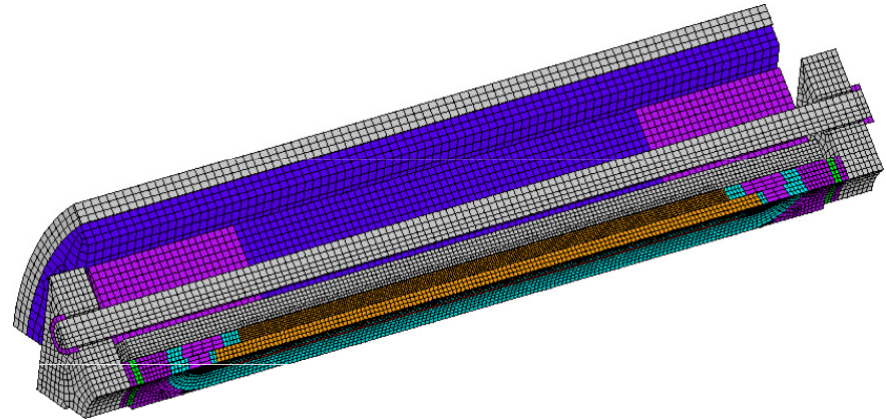
Comparison 2D-3D models



3D mechanical analysis

Aluminum rod tension and coil-pole

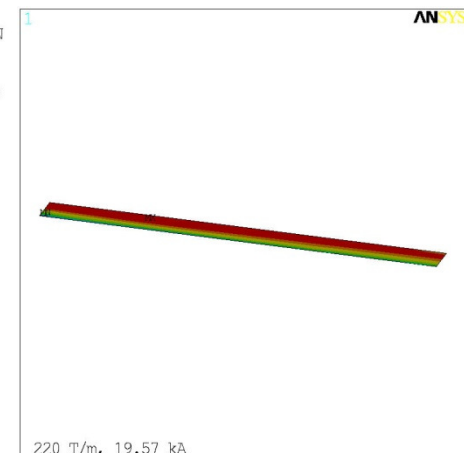
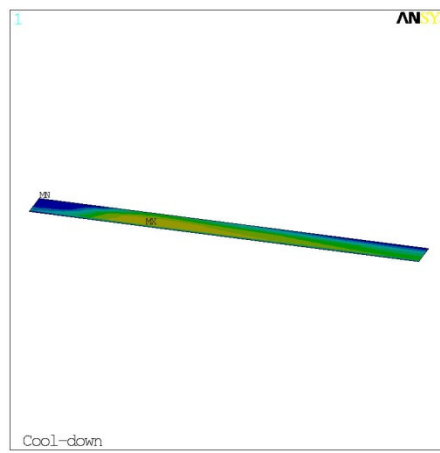
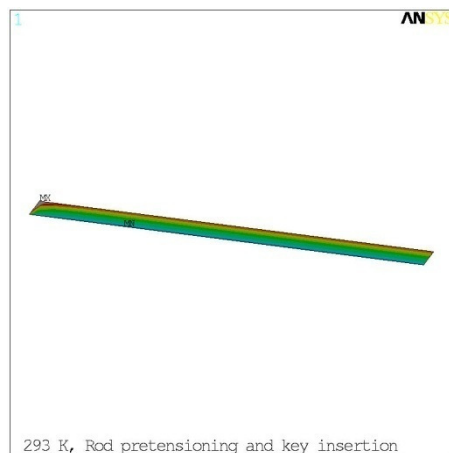
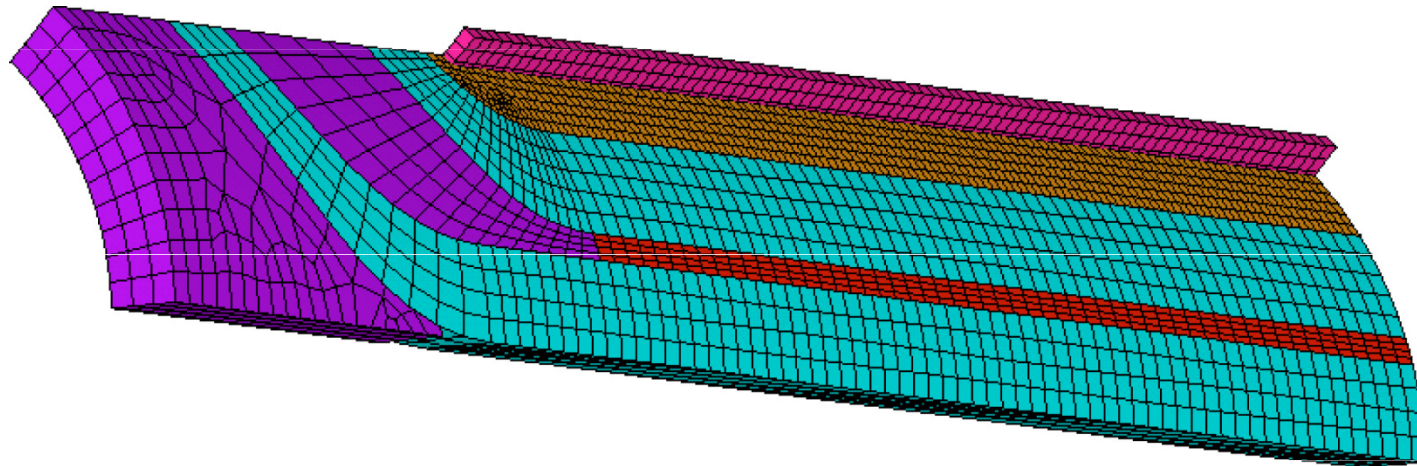
- Pre-loading for 219 T/m
 - E.m. force: 1372 kN
 - 620 kN applied at 4.2 K
 - <20 MPa tension at 219 T/m



3D mechanical analysis

Alignment key collar-coil

- Contact between collar and alignment key



Conclusions

- HQ is a field quality quadrupole with a 120 mm bore and an expected maximum gradient
 - 199 T/m at 4.4 K and 219 T/m at 1.9 K
- The shell structure is based on the experience from TQS and LQS
 - Maintains the coil in contact with the pole in the straight section and in the end region up to short sample
 - Provides alignment to coil and structural components
- The coil peak stress can be maintained below 150 MPa with a pre-load for 180 T/m